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RESEARCH AND DEVELOPMENT OF AN ADVANCED PERSONAL LOAD CARRIAGE SYSTEM PHASES II AND III

Section F: Workshop on Advances in Military Load Carriage

by

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PWGSC Contract No. W7711-5-7273/001/TOS

on behalf of
DEPARTMENT OF NATIONAL DEFENCE

as represented by
Defence and Civil Institute of Environmental Medicine+
1133 Sheppard Avenue West
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October 30, 1997

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Workshop
on
Advances in Personal Load Carriage

Executive Summary

The Workshop on Advances in Personal Load Carriage was held at Queen's University from October 7-10, 1997 and was sponsored by TTCP-TLG-8 and the Defence and Civil Institute for Environmental Medicine The purpose was to bring together researchers with soldier mission command to exchange information between TTCP (NATO) countries and ensure that research developments were in agreement with command expectations Commercial designers were also invited A secondary purpose was to demonstrate the approach being taken by Canada at Queen's University, mainly the development of standardized testing protocols, such as the Load Carriage Simulator

The conference attracted fifty scientists, soldier command, and commercial visitors from 10 countries There were fifteen papers delivered as well as demonstrations of military and commercial systems, with abstracts included in this report. Within the program were also opportunities for discussion of system designs and design features that were important for soldier operational effectiveness At the closing of the meeting, participants completed focus group discussions identifying key design issues in load carriage Ideas for design to overcome current limitations were also discussed, focusing on controlling the weight, cooling the body, reducing the load, off-body load carriage, and protecting the soldier. This information is also included in this report.

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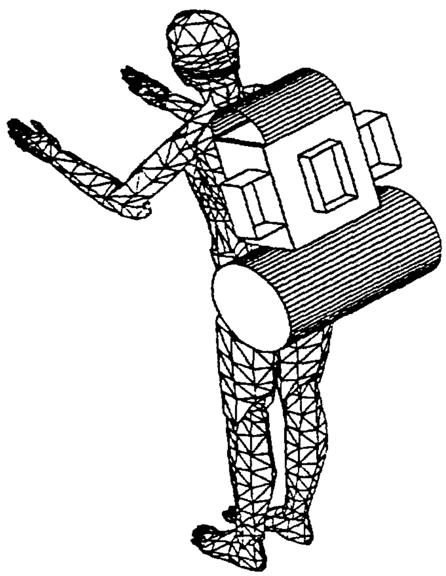
Advances in Military Load Carriage

A Workshop Sponsored by TTCP - TLG-8 and DCIEM



Hosted by the Ergonomics Research Group
Queen's University, Kingston, Ontario, Canada
October 7 - 10, 1996

dciem

National Defence / Défense nationale

Defence and Civil
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INSTITUT DE MÉDECINE ENVIRONNEMENTALE
pour la défense
1133, ave Sheppard ouest
C.P 2000, North York (Ont)
M3M 3B9

It is with great pleasure that I welcome you on behalf of DCIEM and TTCP-TLG8 to a workshop on Advances in Military Load Carriage. We are delighted that Queen's University is willing to act as host and as a major participant of the Workshop. The excellent level of the research at Queen's University will become evident to you as you see the innovative work on standardized assessment and evaluation of load carriage systems which have been developed.

Most countries of the western world are developing, or at least are thinking of developing, new equipment which will bring the infantry soldier into the digital battlefield of the 21st century. If these infantry modernization plans have one thing in common, it is that, for the first time, the infantry soldier and his equipment are being developed as an integrated weapon system. This means that all components of the system must fit and work together, something that load carriage systems of the past and present are not particularly noted for. It was because of this that three years ago DCIEM contracted with Queen's University to take a complete new look at the military load carriage system and come up with the optimal integrated system. This design is still underway but first, standardized methods of assessment had to be developed.

It is hoped that the technology and developments that we share at this meeting can help contribute to better soldier systems of the future. We look forward to the Workshop and to your participation in it. For those who are interested, we would be happy to provide a brief tour at the end of the Workshop for participants who wish to visit DCIEM's facilities in Toronto.

Yours sincerely,

Kenneth N. Ackles

Kenneth N. Ackles, Ph.D.
Chief Scientist, DCIEM

ERGONOMICS RESEARCH GROUP

Queen's University
Kingston, Canada
K7L 3N6

October 1, 1996

Dear Workshop Participants:

It is with great pleasure that we welcome you to Queen's University and the Workshop on Advances in Military Load Carriage sponsored by TTCP-TLG8 and DCIEM.

As your hosts, the Ergonomics Research Group have prepared colourful and interesting presentations, which reflect the variety of methodological approaches we have undertaken in our evaluation of load carriage systems. We have provided the opportunity for you to tour our various laboratories and assessment centres. We look forward to discussing the many issues related to load carriage with you during your time at Queen's University.

Throughout the conference we have developed a wide variety of activities for you to experience the sites and sounds of Kingston, from our military heritage to life at Queen's University. We hope your stay at Queen's is enjoyable, and if there is anything we can help you with during your visit, please do not hesitate to contact us.

Yours truly,

Joan M. Stevenson

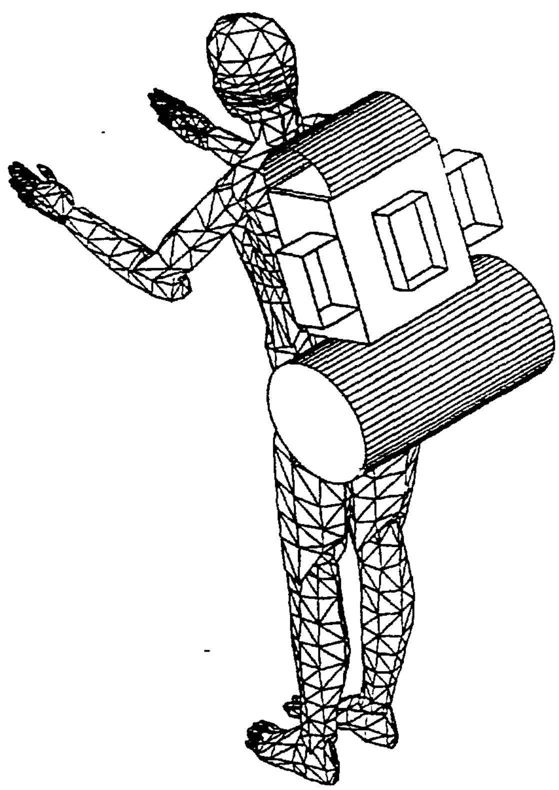
Dr. Joan M. Stevenson, PhD
APLCS Coordinator and Professor

Janice Deakin

Dr. Janice M. Deakin, PhD
Chair, Ergonomics Research Group

JS/st

Advances in Military Load Carriage Workshop



PROGRAM

October 7 - 10, 1996

Queen's University, Kingston, Ontario, Canada

GENERAL INFORMATION

Registration Desk Hours
Lobby of the Donald Gordon Center

Mon. October 7	5:00-7:00pm
Tues. October 8 - Thurs. October 10	8:00-9:00am

Holiday Inn Shuttle

A shuttle van will be available to delegates of the workshop for transportation to the DGC from downtown Kingston. The shuttle van will arrive at the Holiday Inn Waterfront Hotel at 8:20 am and depart at 8:30 am. The shuttle van will also return delegates to the Holiday Inn once the day's sessions are over.

The Donald Gordon Center

Smoking in the Donald Gordon Center is permitted only in "The Pub" which will be open for Workshop socials (5:30 pm-7:00 pm) and again from 8:00 pm - 12:00 am. Delegates who wish to smoke during the workshop are asked to please do so out of doors.

For guests of the Donald Gordon Center, all meals are included in the cost of a night's stay. Delegates who are not staying at the Donald Gordon Center are welcome to join guests for lunch or dinner in the DGC dining room. Please notify the registration desk if you are interested and would like further information. Alternate arrangements have also been made for those wishing to have lunch outside of the Donald Gordon Center. Please inquire at the registration desk.

Social Program

Monday, October 7 — **The Pub, DGC**
20:00hrs - 22:00hrs — Cash Bar

Two free drinks will be provided and snacks will be served.

Tuesday, October 8 — **Old Fort Henry**
18:45hrs — Bus Departs from DGC
19:00-21:30hrs — Dinner

Workshop delegates will be treated to dinner in the Barracks at Old Fort Henry. The meal will consist of soup and salad followed by an entree of braised chicken in a fennel and olive sauce. Delegates should be prepared to enjoy a meal served as it would have been in 1867. Casual wear.

Wednesday, October 9 — **Grizzly Grill**
20:30hrs — Cash Bar

Workshop delegates are invited to join the workshop organizing committee for an evening of pool and casual drinks. The Grizzly Grill is a popular bar in Downtown Kingston. The shuttle van will leave the Donald Gordon Center at 20:15hrs.

Workshop Organizing Committee

Chris Barrick - Conference Co-manager
Lucie Fortier - Conference Co-manager
Jon Doan - Ergonomics Research Group
Joan Stevenson - APLCS Co-ordinator
Sue Reid - Ergonomics Research Group
Dr. Ken Ackles - DCIEM
Major Linda Bossi - DCIEM

Monday October 7

5:00-7:00 p.m. **Registration**, Front Lobby, Donald Gordon Centre

8:00 p.m. **Reception**, "The Pub", Donald Gordon Centre

Tuesday October 8

8:00-9:00 a.m. **Registration**, Front Lobby, Donald Gordon Centre

Morning Session, Conference Room A, Chair: Dr. Janice Deakin

9:00 a.m. **Introductory Remarks**
Dr. Janice Deakin, Ergonomics Research Group, Queen's University, Canada

Welcome & Opening Remarks
Dr. Bill Leggett, Principal, Queen's University, Canada

Dr. Ken Ackles, Chief Scientist, Defence and Civil Institute of Environmental Medicine, Canada

9:15 a.m. ***Canadian Soldier Modernization***
LCol JHJ Levesque, Research and Development, Directorate of Land Requirements, National Defence Headquarters, Canada

9:45 a.m. ***DCIEM's Role in the Soldier Modernization Project: Overview of Internal & External Research***

Ken Ackles, Chief Scientist, Defence and Civil Institute of Environmental Medicine, Canada

Major Linda Bossi, Operational Human Engineering Group, Defence and Civil Institute of Environmental Medicine, Canada

10:15 a.m. ***Queen's Approach to Advanced Personal Load Carriage Systems***

Joan Stevenson, APLCS Coordinator, Queen's University, Canada

10:30 a.m. **Break**

10:45 a.m. ***Overview of U.S. Army Approach to load-carrying equipment***

John Kirk, U.S. Army Natick Research Development and Engineering Center, United States

11:15 a m. ***Generalized Updates and Interests of other Military Guests***

- Belgium
- Israel
- Sweden
- France
- Netherlands
- United Kingdom

11:30 a.m. ***Generalized Updates and Interests of Civilian Guests***

- Arthur D. Little
- The Coleman Co.
- Gentex Inc.
- Humansystems Inc.
- Johnson Worldwide Assoc.
- Loughborough Univeristy
- Quest
- Lincoln Fabrics Ltd.
- META Research
- Ostrom Outdoors
- Pacific Safety Products
- Vortex Packs
- University of Massachussetts
- Heller Institute of Medical Research
- Computing Devices Canada
- Israel Institute of Technology

11:45 a.m. ***Establishing Goals for the Workshop - Identification of Load Carriage Issues***

Janice Deakin, Ergonomics Research Group, Queen's University, Canada

12:00 p.m. **Lunch**

Afternoon Session, Conference Room A, Chair: Dr. Ken Ackles

1:15 p.m. ***Limitations of Human Load Carriage***
Joan Stevenson, APLCS Co-ordinator, Queen's University, Canada

1:45 p.m. ***Guidelines for Design of Personal Load Carriage Systems***
Robert dePencier, Consultant, Canada

2:15 p.m. ***Kit Placement***
Ron Pelot, Department of Industrial Engineering, Technical University of Nova Scotia, Canada

2:45 p.m. **Break**

3:00 p.m. ***The Myth of the Technological Fix***
Gerrit Wilde, Department of Psychology, Queen's University, Canada

3:40 p.m. ***Load Carriage Displays***

- Bill Crawley, Vortex Backpacks, United States
- Major Johan Skullman, FMV, Sweden
- Bill Ostrom, Ostrom Outdoors, Canada

4:00 p.m. **Military Heritage Tour of Kingston**

5:15 p.m **Return to Donald Gordon Centre**

6:45 p.m. **Transportation to Old Fort Henry**

7:00 p.m. **Reception**, The Barracks, Old Fort Henry

7:30 p.m. **Dinner**

Wednesday October 9

Scientific Session I, Conference Room A, Chair: Dr. Ron Pelot

8:40 a.m. ***A methodology in load carriage assessment for design***
Paul Gorzerino, Centre Facteurs Humains, France

9:00 a.m. ***User involvement in human factors design and evaluation***
Robert Webb, David Tack, Humansystems Inc., Canada

9:20 a.m. ***Ideas on military backpack design***
Jeroen van de Water, TNO Human Factors Research Institute, Netherlands

9:40 a.m. ***Human trials testing of load carriage designs***
Jon Doan, F.A.S.T. Trials Project Manager, Ergonomics Research Group, Queen's University, Canada

10:00 a.m. **Break**

Scientific Session II, Conference Room A, Chair: Major Linda Bossi

10:20 a.m. ***The effects of backpack frame type and waist belt usage on the metabolic cost of load carriage***
John P. Obusek, US Army Research Institute of Environemental Medicine, United States

10:40 a.m. ***A biomechanical model of load carriage***
Steve MacNeil, Ergonomics Research Group, Queen's University, Canada

11:00 a.m. ***Optimal Load Distribution***
Ron Pelot, Ergonomics Research Group, Technical Uniersity of Nova Scotia, Canada

11:20 a.m. ***Development of a Design Assessment Protocol for Load Carriage Systems***
Tim Bryant, Chair of Clinical Mechanics, Queen's University, Canada

11:40 a.m. ***Integration of Subjective and Objective Analysis Systems into a Standardized Measurement Approach***
Susan Reid, APLCS Project Manager, Queen's University, Canada

12:00 p.m. **Lunch**

1:30 p.m. **Transportation to Queen's University**

Tour of Research Facilities, Queen's University

1:40 p.m.	GROUP I:	**F.A.S.T. Trials**, Bews Gym, PEC
	GROUP II:	**Portable System**, Walter Light Bldg
	GROUP III:	**Load Carriage Simulator**, Clinical Mechanics
2:20 p.m.	GROUP I:	**Portable System**
	GROUP II:	**Load Carriage Simulator**
	GROUP III:	**F.A.S.T. Trials**
3:00 p.m.	GROUP I:	**Load Carriage Simulator**
	GROUP II:	**F.A.S.T. Trials**
	GROUP III:	**Portable System**

3:40 p.m. **Return to Donald Gordon Centre**

5:30 p.m. **Social**, "The Pub", Donald Gordon Center

6:30 p.m. **Dinner**

Thursday October 10, 1996

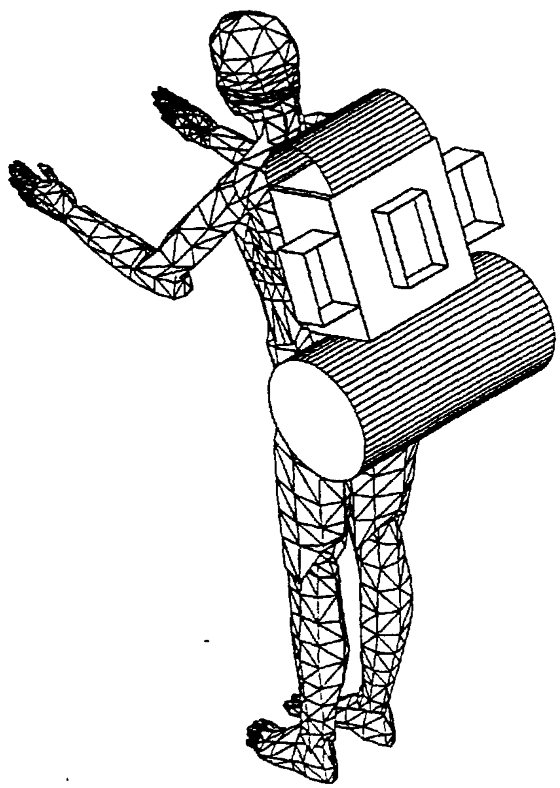
9:00 a.m. **Organization of Focus Groups - Issues of Load Carriage**
Tim Bryant, Chair of Clinical Mechanics, Queen's University, Canada

Ron Pelot, Department of Industrial Engineering, Technical University of Nova Scotia, Canada

Thursday, October 10

9:15 a.m.	**Discussion in Focus Groups**	
10:15 a.m.	**Debriefing from Focus Groups**	
		Tim Bryant, Chair of Clinical Mechanics, Queen's University, Canada
10:45 a.m.	**Break**	
11:00 a.m.	***Future Possibilities in Design of Load Carriage Systems***	
		Robert dePencier, Consultant, Canada
11:30 a.m.	**Closing Remarks**	
		Joan Stevenson, APLCS Co-ordinator, Queen's University, Canada
		Ken Ackles, Chief Scientist, DCIEM, Canada
12:00 p.m.	**Lunch**	
1:00 p.m.	**Departure**	

Advances in Military Load Carriage Workshop



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October 7 - 10, 1996

Queen's University, Kingston, Ontario, Canada

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Canadian Soldier Modernization

LCol J.H.J. Levesque
Directorate of Land Requirements, National Defence Headquarters, Ottawa, Canada

The Canadian Forces is committed to soldier modernization. The aim is to commence the fielding of an integrated soldier ensemble within the next ten years. The ensemble will draw from emerging technologies in the areas of textiles, personal protection, sensory enhancement,. surveillance and target acquisition, information management, communications and systems integration. The target is to effect major improvements in the soldier's lethality, survivability, sustainability, mobility and C4I. The ensemble will be designed for general war. The project will also draw from recent Canadian experience in other operations such as in Bosnia, Croatia, Somalia and Rwanda. The Department of National Defence has begun a comprehensive series of studies and projects in support of soldier modernization. These include a recently completed systems definition study, Operational Analysis into the tactical impact and cost/benefits, human factor and technical research into such areas as Advanced Load Carriage, Individual Portable Power and Helmet Mounted Displays, and physiological/psychological factors. A major R & D effort will be the fielding of 30 system technology demonstrators by the turn of the Century followed by comprehensive troop trials. Canada is working in close cooperation with industry and our NATO and other allies on this project.

DCIEM's Role in the Soldier Modernization Project: Overview of Internal and External Research

Maj. L. Bossi, Dr. K.N. Ackles
Defence and Civil Institute of Environmental Medicine, Toronto, Canada

This presentation will provide a general overview of research and development efforts within CRAD's Soldier Systems Thrust. We wil highlight R & D activities, both in-house and externally contracted, aimed specifically at modernizing and enhancing the protection and capabilities of the individual soldier. This presentation will conclude with a summary of efforts underway to improve the soldier load carriage system for the near-term and for the future.

Queen's Approach to Advanced Personal Load Carriage Systems

J. Stevenson[1], T. Bryant[2], R. Pelot[3], E. Morin[1], R. dePencier[2], G. Reid[1], J. Deakin[1]
[1] Ergonomics Research Group, [2] Clinical Mechanics Group, [3] TUNS- Nova Scotia
Queen's University, Kingston, Canada, K7L 3N6

INTRODUCTION

Queen's University was selected by DCIEM as the research team to assist with the research and development of an advanced personal load carriage system (APLCS) for the Canadian Forces NATO soldier modernization plan. Because of the nature of the project and the nature of Queen's Ergonomics Research Group (ERG), it was possible to pull together an appropriate interdisciplinary team. The team was comprised faculty and staff with skills in systems analysis, design, mechanical engineering and testing, biomechanics, human factors, physiology, electrical engineering, computing and statistics. In addition, the technical skills of the Clinical Mechanics Group combined with the Ergonomics Research Group create a formidable team.

Interdisciplinary research is not an easy matter as coordination and planning are the most difficult aspects. In addition, working in a research laboratories which are in different buildings and on different campuses is indicative the types of problems which will be encountered with the Integrated Protective Clothing and Equipment (IPCE) project as Queen's is a microcosm of larger organizations. The same organizational dilemma will be faced by the military and the industrial consortium as they undertake the APLCS project.

UNDERSTANDING ROLES

The first step in integrating into the military project is to understand our role as a university research team under DCIEM's mandate. Although contracts dictate an action plan, it is important to appreciate the larger vision of the Canadian Forces (CF) and maintain a perspective on the university's role in society. In terms of the CF, there are two concerns: the immediate problems of updating and improving the equipment and clothing soldiers wear, currently called the "Clothe the Soldier" (C.S.) project and to plan for the future IPCE project as part of the Soldier Modernization Plan.

Queen's University's Role. As researchers, despite the difficulties in procuring funds, it is important to appreciate a university's role in society. Because ergonomics is often associated with market-oriented products and work place settings, this creates a situation where service-based research contracts are expected to answer applied research questions. Yet, as researchers, we know that there is a need for answers to basic questions before some applied questions can be answered. For example, what is the issue tolerance of skin or joints before injury occurs? If the answers were known, then load carriage systems could be designed to remain under the tolerance limits so that soldiers/ civilians have less risk of injury.

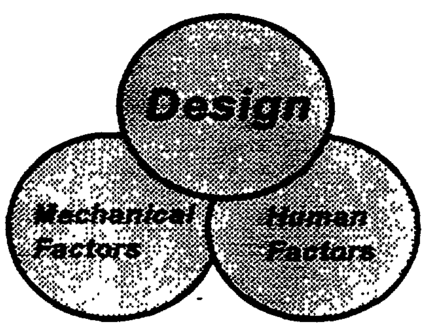
Service Driven Model for APLCS. Since Queen's sees its role are a partnership, not in competition, we developed a strategy whereby our goal was to provide cost effective methods of assessment to optimize human performance and safety which are scientifically credible. This is best accomplished by integrating the mechanical and

Table 1. Mission statement an approach to research, education, and service by Queen's ERG

MISSION of ERG at QUEEN'S	To provide leadership for interdisciplinary research, service and eduction in association with private and public sector institutions to insure scientific integrity of policy and practice relevant to the work environment.
Research	To provide a mechanism for collaborative research in areas of ergonomics, both at the basic and applied levels.
Service	To service the needs of the private and public sectors by means of consultation and training with the principle goal being technology transfer from university to industry.
Education	To provide a catalyst for quality academic programs for Queen's students, the community and society in area of ergonomics.

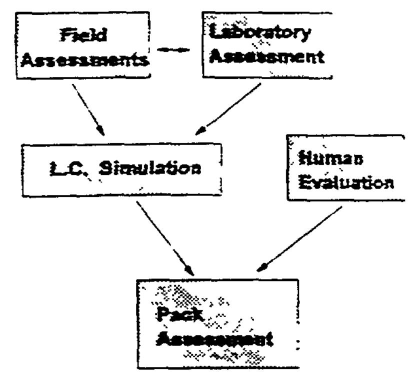
human factors approaches since both mechanical and human factors are important to product design and safety. In addition, exposure of the methodology to peer review and making methods available to the private sector fulfills our overall missions in research, service and education.

Approach to APLCS. Both human factors and mechanical testing are needed to develop and/or evaluate APLCS designs. The dual mandate to answer research questions for both the IPCE and CTS projects simultaneously resulted in the approach shown below. A number of field and laboratory assessments are needed to ensure appropriate mechanical tests and human performance tests are developed. Then, a comparison of human responses to simulations can be used to help set performance criteria or standards for systems based on human tolerance data. Validation of this approach is essential as is continuation of basic research (i.e. biomechanical modelling of loads on the waist or shoulder). This approach has been described as first assessments and standardization tests or (F.A.S.T.) Trials.

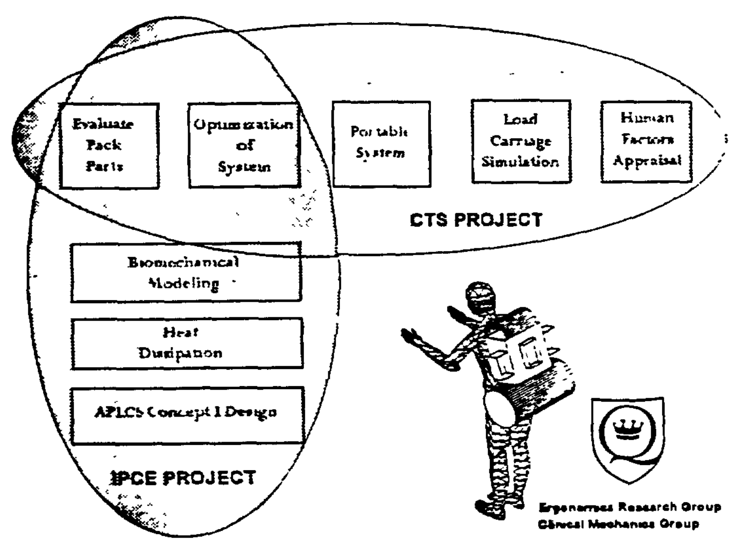


Human Trials. The IPCE and C.S. projects both require the development of measurement systems. Both projects require rapid response to design changes or evaluation of different systems. For human trials an incomplete block statistical method was used to gather information from soldiers. Thus, it is possible to maximize the number of systems while minimize the number of soldiers required to rank them.

Static & Dynamic Simulations. Mechanical systems were constructed to simulate and measure responses to human movement conditions. With this approach, any number of LCS systems can be tested in a standardized manner. In addition, the effect of design, clothing, equipment, fragmentation vests and body size can be evaluated.



Need for Further Research. The first steps of validation of our approach are underway within our current contract. However, validation of the F.A.S.T. trials approach must be made by an outside research group also. In addition we plan to show, through our presentations and tours, the potential to answer more questions as we expand the potential of the current assessment systems. However, it is only through a basic research program which operates in parallel with an applied research program that university scientists can truly help to optimize human performance and safety.



Acknowledgements. Contract support for current work is under the scientific authority of the Defence and Civil Institute of Environmental Medicine (Contract #: W7711-4-7225/01-XSE, 1995 and Contract #: W7711-5-7273/001 -TOS, 1996).

OVERVIEW OF THE U.S. ARMY APPROACH TO LOAD-CARRYING EQUIPMENT

John Kirk
U.S. Army Natick Research Development and Engineering Center, Natick, MA

TOPICS

1. Current Systems
   a. All-Purpose Lightweight Individual Carrying Equipment (ALICE)
   b. Integrated Individual Fighting System (IIFS)

2. Soldier Feedback

   a. User Surveys
   b. Front-End-Analysis

3. Tech Base

   a. Waist Belt Study
   b. Center of Mass Study
   c. Load Distribution Analysis

4. On-Going/Recent Developments

   a. Near Term/Interim Solutions
      1. ETLBV
      2. CMVS
      3. Patrol Pack for ALICE
      4. Butt Pack

   b. Land Warrior

   c. Modular Program
      1. Systems Approach
      2. Acquisition reform
         a. performance specification
         b. development and limited production contract

LIMITATIONS OF HUMAN LOAD CARRIAGE

J.M. Stevenson*, C.M. Barrick*, D.M. Andrews*, and R.P. Pelot**

*School of Physical and Health Education, Queen's University, Kingston, Ontario
**Department of Industrial Engineering, Technical University of Nova Scotia

INTRODUCTION

The purpose of this paper is to provide a short review of the main limitations of human load carriage. Literature reviewed include sources from the military, the civilian scientific community, and civilian-user reviews from the outdoor recreation industry. Military sources include scientific studies and reports on load carriage design and performance by military personnel, and military funded research carried out by civilian scientists primarily within the disciplines of biomechanics, physiology, and ergonomics. Civilian-user reviews have usually been in the form of magazine reports by focus groups who have pilot tested new product lines in the field.

Much of the load carriage research has focused on the establishment of guidelines for acceptable load weights for military personnel. The search for the maximal acceptable weight has traditionally placed emphasis on the amount of weight carried. However, a wide range of factors such as walking speed, distance and duration of the carry, terrain conditions and grade, physical fitness and design of the load carriage equipment, all play important roles in the limits of weight that can be carried safely and productively.

LOAD CARRIAGE LIMITING FACTORS

Load Magnitude - Researchers at the US Naval Research Center[1] determined that there is a linear increase in skeletal muscle damage with increased backpack loads, as indicated by levels of serum creatine phosphokinase produced in muscular effort. High loads (40 kg) have also been shown to be related to significantly higher energy costs over time than lighter loads (25 kg), likely as a result of altered locomotion patterns under heavier loads[2].

Load Placement - Inertial properties of backpacks loaded with 12 kg under six loading configurations (basic load low, basic load high, and added 9.12 kg to either of the sides, top, bottom and front) of the pack[3]. Moderate to large changes in the center of mass were produced by moving the weights from top to bottom, with little differences in moments of inertia.

Cited in a review article on methods of load carriage[4], the energy expenditure during carrying was least when using a yoke across the shoulders, compared to on the hip, on trays, in hand bundles, on the head, and over the shoulder. In another study which compared 7 ways of carrying 30 kg loads over 1 km at 5 km hr^{-1}, carrying the load on the front and back (double pack) incurred the least oxygen cost, whereas carrying loads in the hands incurred the most[5].

The effects of varying positions of load mass on the physical capabilities of infantry soldiers has also been investigated during obstacle course, jumping, sprinting, running, hand-grenade throwing and mobility tests[6]. Results indicated that performance, averaged over all the tasks, was 1.5 to 2% better with an equally distributed mass around the waist compared to mass low or high on the back. Placing the mass high on the back resulted in a poorer performance on the mobility test. In general, higher load placements seem better when hiking is required and lower placements are better for climbing or traversing obstacles where stability is required[7].

Walking speed - Increases in the speed of walking have been associated with greater increases in energy expenditure[8,9]. The speed of movement has also been shown to be as important a factor in causing exhaustion as the weight of load carried [10,11]. Also, in rough terms, walking speeds of over 4 km hr^{-1} reduce the acceptable load by 20 kg per 1 km hr^{-1} of speed[12].

Surface Type - The greater the penetration allowed by the terrain travelled on, the higher the associated energy demands as a result of greater muscle mass usage, added lift work, and forward stooping postures[8] (see Table 1)

Table 1: Energy cost (Watts) of walking at 1.6 m/s for various level terrain types for a 70 kg man with no load[7].

Tarmac road	Dirt road	Light brush	Hard snow	Heavy brush	Swampy bog	Loose sand	Soft snow (15cm)	Soft snow (25cm)
374	401	428	454	508	589	669	785	1005

Load Carriage System Design - Ground reaction forces have been used as output measures for comparing a back load (only) and a double pack load carriage system[13]. It was suggested that differences found between the load weights could have some effect on lower extremity injuries, particularly the metatarsals, and that the gait parameters for the double pack system more closely resembled those for normal walking than the backpack only system. The backpack system caused significantly more forward lean.

Internal and external-frame backpacks have been compared with respect to postural compensation during standing[14], and physiological and perceptual responses during treadmill walking[15]. Although forward trunk lean typically increases with the use of internal frame packs, in order to compensate for the lower load center of mass[14], energy cost and ratings of perceived exertion have been shown to be similar for the two pack types[15].

Other studies have analyzed design features, such as backpack frame length, on the movement of subjects during several walking, running agility, ladder climbing, and standing tests[16], and a variety of measures of 4 frame-pack systems during standing and vertical jumping[17]. Design features such as new shoulder straps, and hip and chest belts allowed 26 subjects to perform strenuous work activities (38 kg and 50 kg at 4.5 km/hr for 4 hr) without difficulty[18]. No significant differences were found in ratings of perceived exertion from the 5th minute to minute 240 of the testing protocols.

Characteristics of the Carrier - Human factors which affect load carriage and carriage system design and evaluation include body anthropometrics and composition (eg. stature, lean body mass); physiological capacity (eg MVO_2, strength, endurance, etc); tolerances of skin to contact pressure; age; gender; and psychophysical factors such as motivation, mental toughness, pain tolerance and perceived exertion[15,18,19]. Ratings of perceived exertion[20] have been used as a measure of local sensations of discomfort associated with strap pinching and rubbing on skin, pressures on bone and muscle, cardio-pulmonary distress, and musclular tension and discomfort of legs, chest, neck and shoulders.

The etiology of low back pain is essentially unknown and likely varies between individuals due to differences in spinal anatomy, movement mechanics, and back pain history. Low back pain and injury have been associated with load carriage during marching tasks[21]. However, in this study of 335 light infantry soldiers who carried 46 kg for 20 km, two thirds of the total 91 reported injuries were foot related, including hot spots, blisters, contusions, abrasions, and plantar fascitis. Other injuries included lower leg sprains and strains and knee pain, injuries which have also been reported elsewhere as a result of load carriage[22,23].

Prolonged pressure on the skin of weight-bearing areas has been hypothesized to be a pathophysiologic factor in the development of pressure ulcers[24], friction blisters[24], deep muscle damage[25], and brachial plexus syndrome or "rucksack palsy" caused by rucksack straps pulling down on the shoulders and into the armpits, thereby pinching the nerves to one or both arms[26]. Low or moderate duration applications of pressure are acceptable for intact skin and damage that might occur is usually reversible However, beyond a certain period of time or level of force, the equilibrium between break-down and regeneration becomes unbalanced, and the net result is tissue breakdown[25]. When subjected to surface pressure, skin and subcutaneous tissues experience a 30% and 100% reduction in blood flow with 4 kPa and 16 kPa of pressure, respectively[27]. Since many physiological studies also rate perceived discomfort, skin pressure and the resultant reduced blood flow, may be important determinants of load carriage tolerance limits.

Gradient - Many physiology-based research projects have used grade to increase the intensity of workload[8,9,28]. However, increased gradient and heavy loads placed on the back both lead to increased foreward trunk lean, a factor which has been shown to increase energy cost during load carriage[12,29], and increase the risk of low back pain[13].

Environmental Conditions - Load carrying ability has been shown to be reduced by 11% in a hot environment (27°)[30]. Researchers have also demonstrated that higher energy expenditure in cold climates is often attributable to the weight, and restrictive effects of multi-layer clothing, and not due to the effects of cold itself. The energy cost of walking in multi-layered, cold weather clothing was shown to increase by 20% over the same task when shorts were worn with the equivalent weight carried on a belt[31].

Duration/Distance - The ill-effects of each of the limitations reported here tend to increase as the duration or distance of the carriage activity increases. Physiologic limits of 50% MVO_2[32], and 35% MVO_2[33] have been suggested for steady state and prolonged activity, respectively.

ACKNOWLEDGEMENTS

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Kit Placement

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Introduction

The fundamental purpose of the soldier's personal load carriage system (PLCS) is to transport articles including basic kit items, rations, ammunition and weapons. The load carriage system should be designed to satisfy the many criteria pertaining to the most effective placement of kit. Conversely, the redesign of certain kit items could improve their portability

General frameworks have been developed to encompass the most important elements of load carriage design. The ABCD system (Access, Balance, Compactness, Danger) applied to civilian pack evaluation reflects most of the considerations for kit placement. In this case, danger refers to the placement of hazardous goods such as the excessive top-loading of a camp fuel container The military's Statement Of Requirements (SOR) stipulates additional and more rigorous standards than civilian packs. However, the standards for optimal kit location have not been thoroughly specified.

Evaluation Framework

A number of criteria should be considered when evaluating kit placement.

bulkiness. various measures include:
- *volume*
- *mass*
- *largest dimension*
- *compressibility*
- *deformability*

accessibility: decomposes into sub-criteria:
- *frequency of use*
- *criticality*
- *ease of replacement*

sturdiness: may affect location
versatility: dropping or adding kit items, adding or removing load carriage components
interference: adversely restricting the soldier's functions, mobility and/or safety
doctrine: any other military practices not governed by the above criteria

The purpose of this analysis is not to prescribe new procedures for kit placement, but to thoroughly dissect loading requirements and strategies with the aim of improving future PLCS design and function. This study focuses on the issues of bulk, access and versatility.

Bulkiness

An inventory of kit items was collated by staff at DCIEM and some typical groupings were defined by season and trade. Masses and approximate dimensions were assigned to each item. The 2RCR (2nd Royal Canadian Regiment) Orders of Dress Operating Procedures was also reviewed for current practices.

To determine whether various loading configurations have a significant effect on the centre of gravity, a simple experiment was conducted. The Canadian rucksack was loaded with typical summer kit, and the centre of gravity measured with a simply supported platform and a scale. The load was then deliberately rearranged to alter the balance, and the centre of gravity shifted noticeably, particularly in the vertical plane.

A simulation model of the rucksack and kit was developed in AutoCAD to facilitate the sensitivity analysis, repeatability, reporting and pack modifications Each kit item was represented by a box with the same mass and approximately correct volume. Eight different loading configurations ranging from approximately 11 to 27 kg. were evaluated. The results are shown in Figure1 (Hall, 1996).

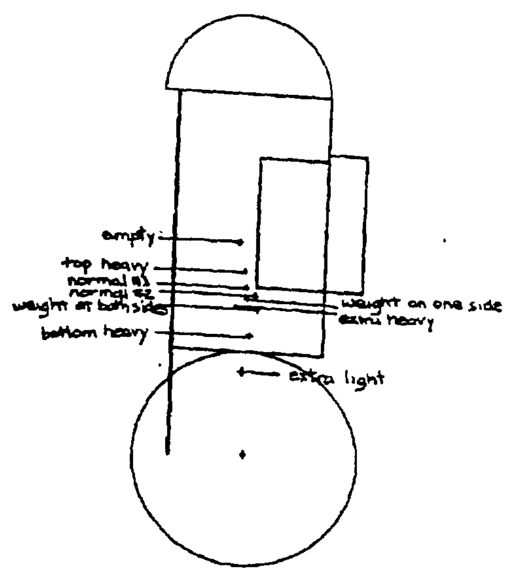

Figure 1. C of G for various loading configurations

The result is that the Centre of Gravity shifts only slightly in the Y (front to back) and X (side to side) planes despite the major reconfiguration of the load, but in the the Z (vertical) direction the range was over 14 cm. This sensitivity to load placement could be exacerbated by heavy munitions load. A review of literature (see Pelot et al., 1995) has shown that CoG shifts can adversely affect the bearer.

Accessibility and Versatility

Although a soldier's comfort and performance may be enhanced by optimizing the centre of gravity of the load, the accessibility of certain kit items and the versatility of the PLCS in adapting to changes in the prescribed loading are at least as important.

Some items need to be accessible during travel times, and others such as sleeping gear are only unpacked at destination. To evaluate the accessibility, two measures are introduced: criticality and frequency of use. The criticality is a major determinant in the placement of kit, as NBC gear and weapons take priority. Items which are frequently used, such as the canteen, should also be easily accessible.

To evaluate these criteria in the field, a questionnaire was administered to approximately twenty soldiers at CFB Petawawa. The survey consisted of a list of kit which would be appropriate for a typical 3-day manoeuvre in the fall. For each kit item, the soldiers were asked to indicate the maximum, minimum and typical number which would be taken on such an exercise. Referring to diagrams of the rucksack and webbing, the soldiers indicated where each article was carried, and the advantages and drawbacks of the location. Specifically, they were asked about the criticality and frequency of use. The answers were elicited in a focus group environment, to be able to elaborate on points and engender discussion.

The soldiers were largely consistent in their placement of kit. Furthermore, they generally adhere to Standard Operating Procedures (SOPs). Certain exceptions were noted however. When allowed to self-determine personal kit items, a wide range of preferences was noted. Some soldiers were willing to bear the increased load to allow additional clothes for warmth or a dry change, while other jettisoned practically all non-essentials. There were a couple of kit items that the soldiers almost unanimously agreed were not useful and/or were in the way.

One common practice is to place the shaving kit and other personal items in the valise (sleeping bag container) which is strapped to the bottom of the rucksack. It is apparently much easier to simply toss the valise in the tent giving immediate access to sleeping bag and the other items stored within. However, the valise was not designed for this, and the implications are that the centre of gravity is shifted to a lower and less desirable position, the valise tends to slip out of its restraining straps, and the balance of the entire load is more unstable.

Many items were categorized as critical, which severely restricts their placement, whereas other items, such as extra socks, can be stuffed just about anywhere. The soldiers provided ratings on the relative frequency of requiring each article. Canteen, rations, binoculars and rain gear are examples of frequently accessed items.

Discussion

A thorough understanding of kit placement practices is essential for effective LCS and kit design. The objective of this study was to determine the main characteristics of kit placement, and to develop a methodology for evaluating all of the pertinent criteria.

The specific results of these studies are only preliminary. Evidently, the centre of gravity is sensitive to kit placement, particularly in the vertical plane, but the translation of this into forces on the soldier has yet to be completed. Furthermore, moments of inertia have been calculated for the various configurations, but the effects on balance have yet to be ascertained.

The criticality of a kit item should be paramount in placing the article, but frequency of use should also be taken into account to facilitate the soldier's task. The load carriage system should be designed to accommodate the widest range of kit possible, based on actual practice as well as prescribed procedures.

Versatility in the LCS, with easily altered configurations, would allow the soldier to respond to a range of missions and environments. However, the design should optimize the basic kit loading as reflected by the above criteria.

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Thanks to Joanne Day and Craig Hall

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A Methodology in Load Carriage Assessment for Design

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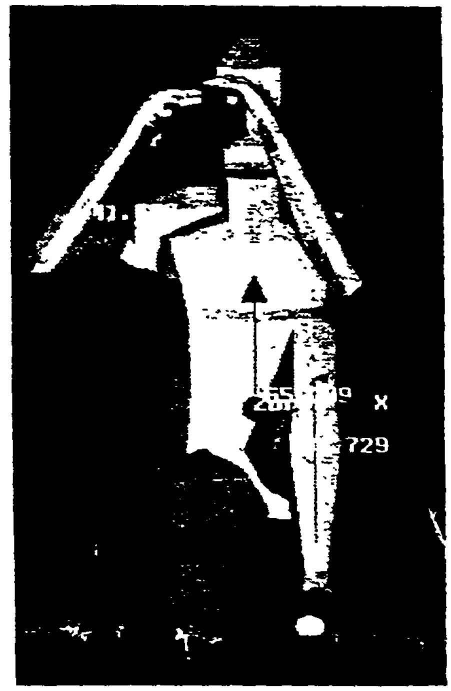
Introduction

The improvement of the infantryman's efficiency includes the optimization of the carried loads distribution (weapons, protective clothing...). During the development of new equipment, it is essential to study, as early as possible, the way to optimize load distribution in order to make the carriage easier with the respect of individual differences.
This will lead to some recommendation for the specification of the loads distribution, the type of clips and the useful adjustment for an optimal use. During the phases of definition and prototype production, the elements previously identified have to be assessed. In order to carry out this work, the Centre Facteur Humain of DSTI use or develop several methods that will be described in this paper.



SAFEWORK picture of a firer

Tools and equipments used.

1° Definition phase.

For the need's description we use computer simulation. In this purpose, the Centre Facteur Humain conducted a study using in order to identify adjustments to take into account on a shoulder carried weapon. This simulation study permitted to analyse interference with the helmet as well as effective weapon handling depending on the firing positions and the fact that the firer was right or left-handed.

Fitter assessing equipment on the course

2° Prototype assessment.

The Centre Facteur Humain is developping an obstacle course similar to the US Army Rechearch Laboratory one. It includes two parallel tracks, 500 meters long, each comprises 20 obstacles. All the measurement instruments are not completed yet.

The parameters that will be recorded includes:
-fitters performance (time recorded, body behaviour using video)
-meteorological parameters
-workload according to physiological parameters (electrocardiogram)
Interview with experimental fitters will constitute the final situation assessment.

Trials methodology has been defined jointly by the Centre Facteur Humain and the US Army Research Laboratory. It has been proposed as a NATO reference. A co-operation programme is also in progress between France and the United Kingdom for studying load carriage using fast speed camera equipment.

A specific hybrid balance and podometric platform is used on the obstacle course. This platform comprises two elements permitting to record pressure, force and torque exerted by the experimental fitter on the ground. Each element is 1 x 1 m large.

Conclusion

Data got from the experiments using the obstacle course will be used to implement simulation software and to improve trials methodology for the assessemnt of the new infantryman's equipments.

Fitter assessing equipment on the course

hybrid balance and podometric platform

User Involvement in Human Factors Design and Evaluation

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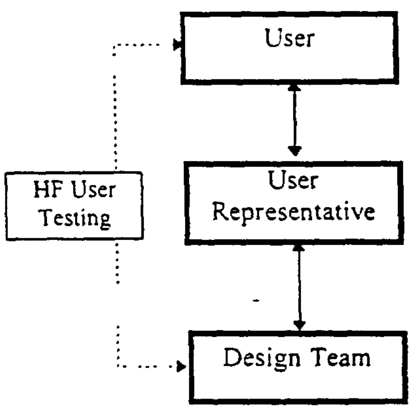
Introduction

The goal of this paper is to outline user testing and, in the presentation, to illustrate this with examples for load carriage equipment.

Human Factors (HF) encompasses many disciplines and viewpoints but a common focus is the user. In this instance, *"user"* is intended to mean the individuals that will actually use the product and not the purchasing organization or its representative. In a free market, failure to meet user needs will result in the user, as both consumer and purchaser, simply choosing another product For defence or any major corporate procurement context, the end user does not have this choice Consequently, some other mechanism must be substituted to ensure that user needs are met.



User testing

The concepts of *'Usability'*, *'User-friendliness'*, *'Utility'* and *'User acceptance'* are all interrelated but the general focus is to provide products (and systems) which are both useful and easy to use by the target user group for all critical operational and maintenance tasks.

Usability assessments should determine the degree to which representative users performing representative tasks under representative conditions will:

- Perform without errors or delays.
- Find the product and its features useful.
- Need additional training.
- Accept the appearance of product.
- Find the product compatible with other products with which it must be used.
- Find the product and its features easy to use
- Find the product safe to use.
- Be able to meet physiological demands.
- Find the product comfortable.

User performance and system effectiveness issues are more important than simple user acceptance. Even though users may prefer a feature, if that feature interferes with performance, or is high cost for little performance benefit, then usability reviews and testing should reveal this trade-off. Sometimes user preferences and user performance may be contradictory. However, user preferences may determine purchasing behavior and probability of use when a choice exists. This means user preferences cannot be ignored even when the less preferred option shows clear performance advantages.

Inevitably, design results in usability trade-offs which can affect task and mission performance in a variety of ways These inter-relationships are often difficult to predict For example, a fragmentation vest that is perceived as *'useful'* (perhaps in terms of ballistic protection) is less likely to be used if not *'user friendly'* (perhaps uncomfortable, high thermal demands and difficult to adjust). Probability of use may be further reduced if the item is perceived as having an inappropriate appearance (perhaps in terms of its being 'un-military'). In both cases, contrasting usability characteristics can ultimately undermine intended design objectives in terms of user performance or protection and mission effectiveness. Many products are multi-function in load carriage terms ballistic protection may serve to carry loads, be part of the overall load carried, and must be compatible not only with other load carriage devices such as a rucksack but also other equipment items.

User testing can be employed in several roles:

- <u>Design</u>
  Determination of user needs
  Concept validation
  Feedback on successive design versions
  User trade-off assessment
- <u>Procurement</u>
  Selection of COTS products
  Monitoring of development progress
  Acceptance of custom designs
- <u>Research</u>
  Identification of user related issues

In combination, use of HF guidelines, reviews and testing should be used to reveal potential problems as early in the design cycle as possible Usability reviews and testing can employ expert evaluations of product features and assess task related behavior as well as solicit user ratings. Inexpensive, rapid, iterative usability reviews and table top assessments can reveal HF oversights well before sub-system and system integration.

Most products do not stand alone but, by design or accident, form part of a system. Every item will need to be evaluated in conjunction with other items. On the other hand, the need to trap compatibility issues early on must be balanced against the need to minimize extensive and time consuming testing of every product.

Prioritization of items for usability assessment and approaches to assessment will need to be made according to the complexity and state of development of the product item and the potential impact on the user or mission effectiveness. Usability reviews and testing should be conducted at a level of representation that is appropriate to the stage of development of the product, sub-system or system of which it is part. Several approaches can be combined. These approaches should be detailed in a Human Factors Program Plan (HFPP) and can include·

- HF guidelines for usability and compatibility for each item within the overall system concept. These guidelines can be used during the design review process (prior to any testing) and to short list Commercial Off The Shelf (COTS) products.
- Rapid iterative table top assessment sessions early in the design cycle. These sessions should employ appropriate Subject Matter Experts (SMEs) and HF specialists working in conjunction with the design team. During these sessions, the review team will systematically step through critical tasks while considering compatibility, utility, usability and training issues. The level of representation will vary with the nature of the product. COTS products can be reviewed and tested in their final form. New products may be available only as prototypes or even artists sketches. Several related items may be assessed in parallel.
- Review of the design product in elementary mock up form with a representative user group. Walk through the use of the product on a task by task basis. Capture of data on usability, utility, training and compatibility related problems. Capture of possible impact of the new technology on staffing, tactics, etc. Provision of design feedback.

As the design progresses, further design reviews and guidance from an HF perspective can be provided, according to a schedule agreed with the design group. At appropriate stages, mockups of increasing sophistication can be used with representative user groups to capture data on usability , compatibility, utility, etc. In the initial design stages, data capture will likely use focus groups and standardized rating scales. In the later design stages, as required, data capture will likely use standardized task related testing procedures with more objective data such as donning and doffing times, video of selected tasks such as ability to sight a weapon in prone firing positions, or data on core temperature for physically demanding tasks. Selecting participants for such testing will be critical. Issues include:

- <u>Choice of person</u>
  Skills, attitudes, experience (tasks and product).
  Number of participants
  Physical characteristics: strength, size, flexibility
  Perceptual and cognitive characteristics: visual acuity, hearing, memory.
- <u>Familiarization</u>
  Product features and purpose
  Test procedures
  Baseline skills

Methodological choices presume the presence of a baseline task analysis and include:

- <u>Simulation approach</u>
  Sketches, CADD, mock-up, prototype
  (Fragility, appearance, functionality)
- <u>Interaction method</u>
  Group vs individual, remote vs face to face, designers present or absent
- <u>Scenarios</u>
  Fixed vs free, task vs feature
- <u>Data capture method</u>
  Interview, focus group, questionnaire, self-report, observer, other

The general sequence of user testing should be detailed in both an overall Master or System. In some cases the HFPP will in turn comprise a nested set of Component and Sub-system HFPP's.

As development progresses from the design of individual items to the integration of these items into sub-systems and then whole systems, the same cycle of expert review, focus group review, and standardized user testing should be followed. The final stage will be field testing of the system as a whole, though it is possible that limited field testing may be possible and desirable for some items prior to the final, whole system field test.

If the philosophy and procedures outlined are followed then the chances of discovering major user related design oversights late in the development cycle should be significantly reduced.

IDEAS ON MILITARY BACKPACK DESIGN

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Introduction

The external load on a soldier is mainly influenced by the way of carrying the load, the characteristics of the terrain, the load mass and the walking velocity.[1] As the terrain type and the walking velocity can be considered as fixed, we can only influence the external load on the soldier by altering the way of load carriage and the load mass. The latter implies a lowering of the personal equipment mass or a reduction in the number of items that the soldier needs. Developments related to Soldier Modernization, however, indicate an increase of personal equipment with the soldier's personal computer system, personal cooling system, body armour and power supply system. Thus a significant reduction of total equipment mass is not expected. Finding better ways for load carriage appears to be necessary for improving the soldier's carrying capacity. In this paper some ideas are presented that can contribute to this.

Backpack obstructions

The load carriage system, of which the backpack is a part, interferes with human performance through five effects: mass increase, obstruction, balance disturbance, volume increase and medical disorders like rucksack palsy, local discomfort and back injuries.[1,2]

The mass of a backpack itself is only a fraction of the total mass of the backpack and the load. Great improvements can not be reached by reducing the backpack's weight. However, every bit helps. Future (SMP) developments may allow the backpack to be integrated with body armour vests or sleeping and shelter systems, which can lead to a substantial overall mass reduction.

The movements of the trunk and arms are limited by a carriage system with 10-20%.[1] This can be improved by moving the shoulder straps towards the neck. A more flexible framework can lower the rotational stiffness. Bending the trunk leads to a shift of load distribution from the hips to the shoulders. This will possibly force the soldier to straighten his back and to bend forward by pelvis rotation.

Carrying load on the back results in a postural adaptation by rotating the trunk forward so that the resulting center of gravity lays above the hips to regain balance. This causes extra energy cost. When the load is located high on the back the forward rotation is smaller, but then more stability problems arise. This is only favourable for well passable terrain types. The best solution is to distribute one half of the load (low) on the front of the body and the other half (low) on the back, so that the natural position remains.

Voluminous equipment items, like the sleeping bag, can hinder the soldier in performing special tasks. Especially large loads on the front of the body interfere with tasks to be performed by the hands and are an obstruction for taking cover.

Rucksack palsy, local discomfort and back pain and injury can highly reduce the soldier's performance. Rucksack palsy can be avoided by lowering the load on the shoulders. Local discomfort like shoulder pressure sores can be lessened by reducing the load on the shoulders or by increasing the shoulder strap surface. When the spine is relieved of the load, back pain should occur less. For these reasons it is better to let the load rest mainly on the hips.

Load on the hips

Hip belts are traditionally used for supporting the load by the hips. By firmly tightening the belt, the load is mainly transduced by a shear force to the sides of the hips. Assuming a friction constant of 0.2, the pressure force on the hips needs to be five times higher than the load force. Therefore it would be much better to let the load force exert on surfaces perpendicular to the gravity vector. The only explicit surfaces of the upright human body of that kind are the top of the head and the shoulders. Since we don't want to use those spots, better fixing methods have to be found for the hips. A possible way is to use the upper edges of the two hipbones, in combination with a shear/pressure point on the dorsal side of the pelvis and sacral vertebrae. A semi rigid brace like device, possibly custom fit, might be used for this (Figure 1). To load the hipbones equally, the brace has to be loaded at the center of the sides of the pelvis by the use of a rigid bow that is connected to the brace with bearings, so that it can rotate in the sagittal plane. In this way no momentum is transduced from the frame to the brace that can lead to unwanted pressure spots on the hipbones. During walking the pelvis rotates in all three directions. Owing to this, the pelvis moves relative to the trunk. To let the backpack adjust to this relative motion, hinges must be integrated into the backpack frame. One double beared hinge is placed between the bow and the upper frame. This hinge permits rotations in the frontal plane. Transversal rotations can be taken by axial bending of the upper framework. Sagittal rotation is taken by the hinges between the brace and the bow.

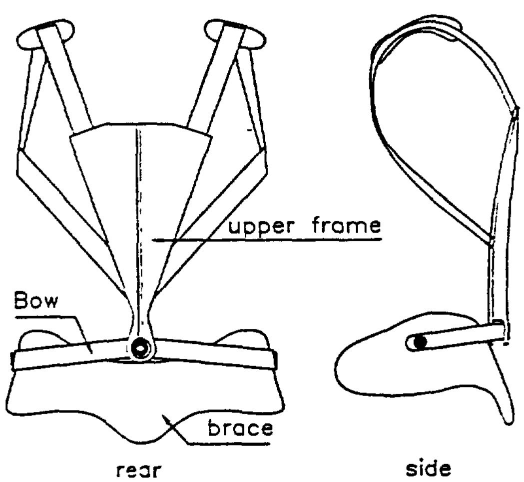

Figure 1 Proposed backpack frame, rear view and side view.

Shoulder load

Part of the load must be carried by the shoulders for two reasons: to stabilize the load and to reduce the pressure on the hipbones. The load force should exert perpendicular to the shoulder surface, to minimize shear stress. Rigid (custom made) cups with a relatively large surface are proposed for shoulder exertion (Figure 2). If the shoulder straps can slide frictionless over these cups then shear stress is banished.

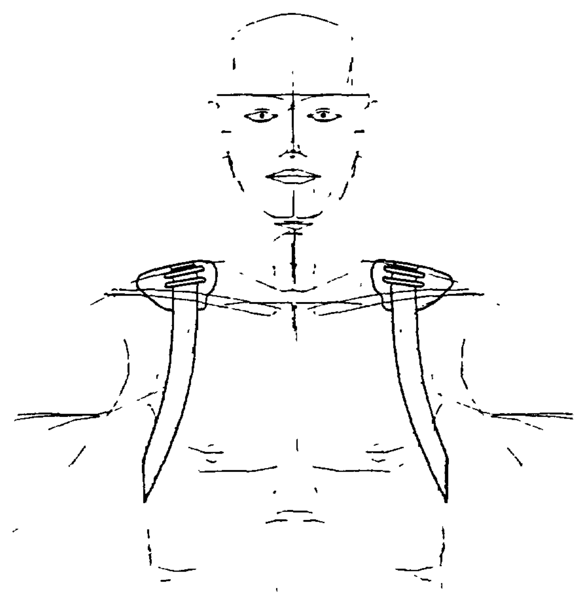

Figure 2 Rigid cups for shoulder load distribution, over which the straps can slide.

Adjustment of the load distribution between the shoulders and the pelvis should be possible during walking. For this an easy to handle device must be integrated to change the length of the upper frame or lengths of the shoulder straps.

Discussion

None of the presented ideas have been tested yet. Problems can arise at the hipbones due to pressure sores, although it has been shown that the hips are less sensitive to pressure than the shoulders by a factor of three.[3] Theoretically no belt is needed at the front side of the brace if the hip brace is very stiff, well fit and the hipbones allow good load support. If not, the brace must be tightened with a front belt.

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Human Trials Testing of Load Carriage Designs

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Introduction

The goal in design is to meet the needs of the user. In the research and design of load carriage systems it is vital to effectively elicit human input about comfort, features, and fit from experienced subjects. In this study, a standardized human testing protocol was developed to obtain this user feedback and to relate these results to testing performed with the load carriage simulator (LC Sim).

This testing is a component of the Advanced Personal Load Carriage System (APLCS) research and development project being carried out by the Ergonomics Research Group (ERG) at Queen's University under contract from the Defence and Civil Institute of Environmental Medicine (DCIEM).

FAST Trials

The First Assessment and Standardized Testing (FAST) Trials developed by ERG were designed to act as an intermediate test in the development of an APLCS (Figure 1). FAST Trials are hoped to be a cost effective and efficient method to gather preliminary information which can help in early design phases or as part of an initial screening phase Objective testing with the LC Sim allows the ERG team to evaluate a large number of potentially suitable APLCS designs and to reduce this sample size to a number which is more practical for human testing.

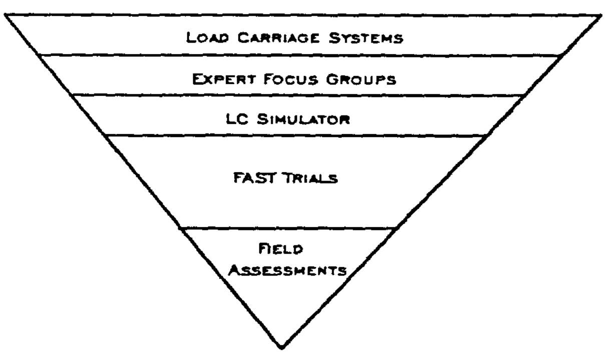

Figure 1. Concept of FAST Trials.

Once this approach is validated by a different research group the LC Sim findings combined with the results from the FAST Trials would reduce the time and preparations necessary to conduct military field trials on an extensive number of systems.

Development of FAST Trials

During previous phases of this contract, the ERG team conducted three separate human tests :

Mobility Circuit - The mobility circuit was developed to test the comfort and load control performance of load carriage systems during a series of physical tests which required the subjects to combine speed, balance, and quick changes of direction over a range of motions (Figure 2). Subjects were asked to rate their stability, balance, comfort, and freedom of movement

Figure 2. Mobility Circuit - Fence Climb

Focus Groups - The APLCS researchers also developed questions for numerous focus groups to improve our understanding of load carriage requirements and personal preferences of expert users The topics discussed included load placement, operational requirements, system integration, and acceptance of design features.

Extended March Circuit - This study was conducted to acquire data to evaluate pack comfort and fit on an extended march, as well as to determine baseline settings for posture and strap force tensions, to be used as standardized inputs for objective pack testing on the APLCS LC Sim.

Postural data were gathered by video and force plate during a static stance test (Figure 3). Strap force tensions were measured by means of in-line strain gauges at the mid point and end of a 6 km march. All subjects were timed and also filled out a survey evaluating pack features and personal discomfort.

Figure 3. Extended March - Posture Analysis

FAST Trial Methodology

The APLCS FAST Trials combined features of the previous three human tests with new measurement systems and more relevant military tasks.

Instrumentation - All subjects were instrumented with skin surface thermistors to record temperature data (Figure 4). During the testing, subjects also had core temperatures recorded at intervals by means of an infrared tympanic temperature probe. Heart rate measurements were also sampled during the test, and all packs were outfitted with strain gauges for strap force readings. Video recordings of subject walking and standing in marching order were used for postural analysis.

Figure 4. Temperature Instrumented Subject

Marching Order Testing - The testing circuit consisted of five 1000 m march laps. After a subject completed each lap of the march, they performed a randomly selected agility task from the following list :

- Bent Balance Beam/Boulder Hop
- Straight Balance Beam
- Fence Climb/Agility Run
- Uphill Ramp/Sidehill Ramp
- Static Tasks

Battle Order Testing - After doffing the load carriage system, subjects were asked to perform a series of high agility battle order tasks (Figure 5). These tasks were

- Vertical Mousehole
- Horizontal Mousehole
- Leopard Crawl
- Over and Under
- Static Tasks

Subjects then performed the agility tasks from the marching order circuit in a continuous fashion.

Figure 5. Battle Order Testing - Grenade Toss

Questionnaires - Subjects completed simple questionnaires following each task, marching or battle order. Summary questionnaires were completed following testing in each of the military orders.

Focus Groups - On the final day of testing, subjects completed a comparison questionnaire evaluating the packs tested, and then discussed positive and negative features in load carriage designs.

Future Testing

All FAST Trails testing that has been performed to date has focused on validating objective results from the LC Sim with responses from expert human subjects. To insure that FAST Trials are repeatable and reliable, an outside research lab should be asked should be asked to test the same systems to validate FAST Trial rankings prior to future APLCS field studies.

Performed under contract from Defence and Civil Institute of Environmental Medicine (DCIEM Contract # W7711-4-7225/01-XSE).

Thanks to Major Linda Bossi, Lucie Fortier, Alan Rigby , James Fry, Tammy Eger, Timo Rantala, Dr. J. Deakin, Sue Reid, and the soldiers of the 1st Canadian Signals Regiment and the 1st Canadian Light Infantry Battalion.

THE EFFECTS OF BACKPACK FRAME TYPE AND WAIST BELT USAGE ON THE METABOLIC COST OF LOAD CARRIAGE

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The effects of waist belt use and backpack type on steady state metabolic energy cost was examined during walking while carrying a heavy load in both external and internal frame backpacks. Twelve male and 2 female active duty soldiers (mean age 23.6 ±4.5 years) participated in this study. A standard U.S. Army all-purpose, lightweight, individual, carrying equipment (ALICE) pack (weight = 2.9 kg, volume = 73,742 cc) was used as the external frame pack. A Mountain Smith Crestone II (weight = 3.2 kg, volume = 88,490 cc) was used as the internal frame pack. Although comparable in total volume and weight, the external dimensions of the two packs differ considerably. The Mountain Smith pack is greater than the ALICE pack in the vertical dimension (91 cm vs. 51 cm) while the ALICE pack is greater than the Mountain Smith pack in the front to rear dimension (35 cm vs. 23 cm). Both packs were loaded with 34 kg of bagged steel and lead shot which was placed centrally within the pack and maintained in position with foam blocks packed tightly around the added mass. The centers of mass of the loaded packs were then determined using a balance board technique.

Over 2 non-successive days, subjects walked on a level treadmill for approximately 5 minutes in each of 5 pack/belt conditions (no pack, ALICE with belt, ALICE without belt, Mountain Smith with belt, Mountain Smith without belt) at 4.8, 5.6, and 6.4 kph. Immediately prior to each test, the total weight of the subject and pack was determined. The order of presentation of the pack/belt conditions was randomized while treadmill speed was increased from slowest to fastest. A custom, open circuit spirometry system was used to determine the rate of oxygen consumption ($\dot{V}O_2$) at 30 second intervals during the final 90 seconds of each experimental condition. The rate of oxygen consumption for a condition is given as the mean of the three sample values for that condition. The steady state metabolic cost is expressed as the mass specific rate of oxygen consumption ($\mathrm{ml \cdot min^{-1} \cdot kg^{-1}}$), which was obtained by dividing the mean $\dot{V}O_2$ for each condition by the total weight of the subject plus pack.

Results of a 3 factor ANOVA (treadmill speed, pack type, belt use) for repeated measures revealed main effects for treadmill speed ($p \leq 0.001$) and pack type ($p \leq .01$). The mass specific rate of oxygen consumption was found to be 19% higher in the 5.6 kph speed condition compared to the 4.8 kph condition and 34% higher in the 6.4 kph speed condition compared to the 5.6 kph condition. The mass specific rate of oxygen consumption for the Mountain Smith pack was 6.4% lower than the ALICE pack (see Figure 1). No significant differences in the mass specific rate of oxygen consumption were demonstrated due to the wearing of the pack waist belt. No significant interactions were found.

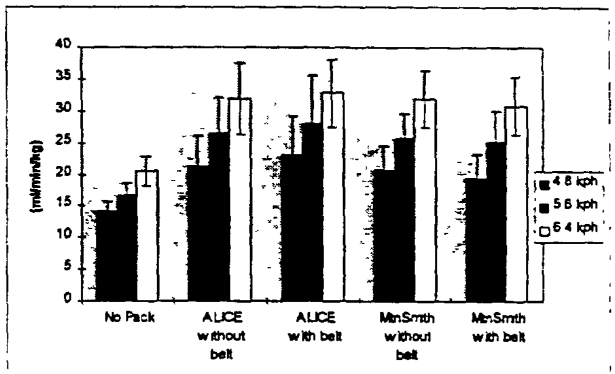

Figure 1 Mass specific rate of oxygen consumption for each treadmill speed by pack type and belt condition.

The ALICE pack, due to its geometry, load placement, and external frame, had its center of mass markedly lower and further away from the subject's body than the Mountain Smith pack. This suggests backpack center of mass location relative to the pack wearer may be an important factor in determining the metabolic cost of carrying a given load. Alternatively, differences in pressure distribution among the shoulders, back, and hips that are due to varying frame configuration may account for the differences in mass specific metabolic cost. Further biomechanical analysis is being performed to examine the effects of pack type and belt use on load carriage kinematics and kinetics, and body contact pressures. Additional studies are planned to investigate the effects of systematic alterations in pack center of mass on mass specific metabolic cost.

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A Biomechanical Model of Load Carriage

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Introduction

The research and development of a new Advanced Personal Load Carriage System (APLCS) for the troops of the Canadian Forces (CF) was tasked to the Ergonomics Research Group at Queen's University by the Defence and Civil Institute of Environmental Medicine (DCIEM).[1] The project incorporated results from human and standardized simulator testing to analyse the features and functions of current military and civilian load carriage systems and to understand the demands of load carriage

In order to interpret the pressure distribution data and strap force measurements collected during simulator testing, a biomechanical model was developed to describe the force distribution from the torso to the pack From this, it was possible to predict how the torso and pack forces interacted in various configurations

Data Collection

Data were collected by mounting each load carriage system on the Load Carriage (LC) simulator This simulator replicated walking by moving a model torso with pneumatic actuators During dynamic testing, force transducers were inserted in the shoulder straps and waist belt of the LC to measure strap forces A FASTRAK™ system was used to collect position data which was interpreted into a relative motion measurement for each LC suspension system while TEKSCAN™ pressure sensing arrays collected contact pressure areas and magnitudes

Biomechanical Model

A free body diagram of a standard pack is shown in Figure 1.The x-y coordinate system describes the long axis of the pack from which the weight vector is inclined at an angle γ. The shoulder strap forces are shown as T2 and T1 inclined at angles $\theta 2$ and $\theta 1$ respectively. The upper strap force, T2, is resolved into components in the x and y directions (T2h and T2y respectively) In addition to the weight and strap force vectors acting on the pack, Fh is the normal reaction force in the lower back due to the lumbar pad Friction between the pack itself and the body is ignored.

The shoulder is modelled as a pulley with friction (Figure 1) The strap tensions, T1 and T2, are not necessarily equal due to the frictional force (Ff) The shoulder reaction force (S) maintains T1 and T2 in equilibrium.

In order to solve the equilibrium conditions for the system, it is necessary to provide geometric measurements and two external force measurements In this model, the lower strap force (T1) was obtained directly from the shoulder strap transducer during testing The other external force was the pack weight, W. Human testing photographs of each pack were used to measure strap attachment locations (L1, L2, L3), inclination of the load (γ), load offset (a), and shoulder strap angles ($\beta 1$, $\beta 2$) The system of equations was solved using a small spreadsheet program. The program output solved a number of variables including the shoulder and lumbar reaction forces for each pack in the configuration tested

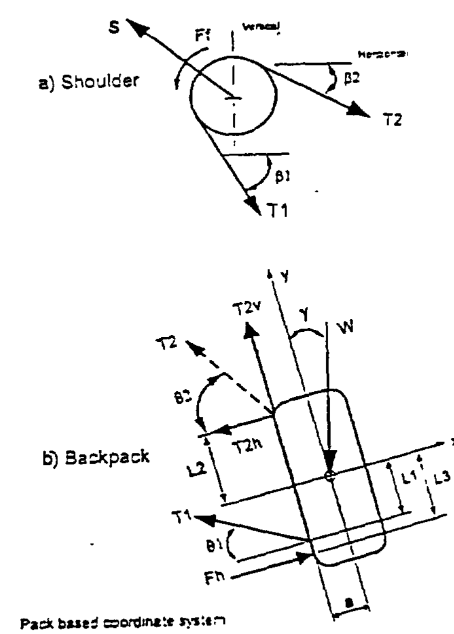

Figure 1 Free Body Diagram of the Pack and Shoulder.

Results and Discussion

A brief summary of results for the model is shown in Table 1. Shoulder reaction force and lumbar force computed for each pack are also shown In all cases, significant forces were apparent for both regions Shoulder reaction forces ranged from 293 N to 361 N and lumbar reaction forces ranged from 172 N to 244 N Shoulder reaction forces were consistent with the inclination angle of the weight vector. As the load angle (γ) approached 0, a larger shoulder force was evident. For example, pack B had a load angle of 12° and a shoulder reaction force of 361 N, while pack A had a load angle of 26° and a shoulder reaction force of only 297 N.

Reaction forces were normalized for the true pack load, since these varied approximately 5% between packs Force factors were calculated in Table 1 by dividing the reaction force by the pack load All packs required a total force which exceeded the pack weight by 44% to 88% Packs B and C required a larger body force than the other three, a result influenced by the geometric effect of the small pack angle (γ) seen in these two cases. An apparent optimal body load case would be a shoulder load factor of 1 0 and a lumbar load factor of 0 4 for a total load factor of 1.4

The load distribution between the shoulder and lumbar regions is also shown in Table 1. The distribution is computed on the basis of the vertical components of the respective reaction forces This distribution is often reported as an expression of "load sharing" between the shoulders and back. Load distributions were typically 80 % shoulder : 20% lumbar, and were also sensitive to pack angle. Distribution of load onto the shoulders increased as pack angle decreased. This shoulder load was further divided to the upper and lower straps, as shown in Table 1. In most cases, the upper strap transmitted 60% of the load and the lower strap 20%

In all packs, a friction force was present at the shoulder. This value more accurately represents shear forces transmitted to the torso through contact between the shoulder strap and underlying clothing. Values ranged from 11.0 N to 61.25 N per shoulder. In 4 of 5 cases, the force resisted downward motion of the lower strap, but in pack A the negative value of the force indicated that it resisted rearward motion of the upper strap. This reflects the unusual design of the upper strap fixation in this pack, since it was only attached to the frame at a point higher than the shoulder

		P	A	C	K	S
		A	B	C	D	E
Pack						
Load	N	322	331	327	318	318
Inclination	°	26	12	18	23	20
Forces						
Shoulder	N	297	361	342	293	303
Lumbar	N	206	244	221	172	183
Total	N	503	605	563	465	486
Force Factors						
Shoulder		0 92	1.12	1 06	0 91	0 94
Lumbar		0 64	0 76	0 69	0 53	0 57
Total		1 56	1 88	1 75	1 44	1 51
Load Distribution						
Lumbar	%	29	16	21	22	20
Shoulder	%	71	84	79	78	80
Upper Strap	%	*40*	*49*	*61*	*59*	*59*
Lower Strap	%	*31*	*35*	*18*	*20*	*21*

Table 1 Summary of biomechanical model results for five test packs

Performed under contract from the Defence and Civil Institute of Environmental Medicine (DCIEM Contract #W7711-4-7225/01-XSE, 1995-1996.)

Thanks to Sue Reid, Christine Barrick, Jon Doan, and Steve MacNeil.

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Development of a Design Assessment Protocol for Load Carriage Systems

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INTRODUCTION

A comprehensive measurement system for load carriage evaluation was developed consisting of human input with respect to comfort, features and fit, as well as a standardized measurement system using a computer-controlled Load Carriage (LC) simulator. The LC simulator had been programmed to a walking cadence of 3 km/hr using computer controlled pneumatic actuators (Figure 1) The mannikin was instrumented to determine the relative motion between the pack and the torso using FASTRAK™ electromagnetic sensors. Custom strain gauges were designed to measure strap forces, and the TEKSCAN™ pressure sensor system was used to assess contact pressures between the torso and the pack suspension elements. Based on strap fores, body incline, weight in the pack and anthropometric measures of the pack and mannikin, a biomechanical model was developed to predict the shoulder and lumbar joint reaction forces.

The purpose of this study was to validate the measurement systems used in the LC simulator under both static and dynamic conditions, and to conduct a sensitivity analysis of the biomechanical model used to evaluate shoulder and lumbar forces.

METHOD AND RESULTS

In order to accomplish the first objective, independent measurement strategies were formed for each of the LC Simulator output measures. The second objective of validating the biomechanical model was initiated by developing a standardized jig for shoulder strap testing where strap forces, pressures, shoulder geometry and pack conditions could be evaluated independently.

Strap Transducers. Custom-built shoulder strap and waist belt force transducers (Figure 2) were used in static and dynamic conditions to assess standardized weights The calibration algorithms were gauged dependent and highly linear ($R^2 > .9995$), with a small error (2.7 N) and were very stable over time in static testing. Under dynamic conditions the maximum standard deviation within tests was 0.9 N and across tests was 2.3 N with less than 4% decay over 1200 cycles.

Figure 1. Load Carriage Simulator. Computer controlled pneumatic actuators drive an instrumented human torso.

Figure 2. Strap Force Transducers. Shoulder straps and waist belt strap forces are measured *in situ*.

Pressure Measurements. The TEKSCAN™ Pressure Sensor System (Figure 3) under static conditions was more stable in average pressure and area of coverage than peak pressures, with the absolute value of peak pressures being more responsive to wrinkles in shirts or buckles. During dynamic conditions, over 1200 seconds of simulated walking trials, the SEM for average pressures was .5 kPa to 1.3 kPa depending on the location and pack characteristics. Peak values were less stable (SEM of 3.7 kPa to 12.6 kPa), dropped in magnitude over time, and were better suited to identifying pressure points.

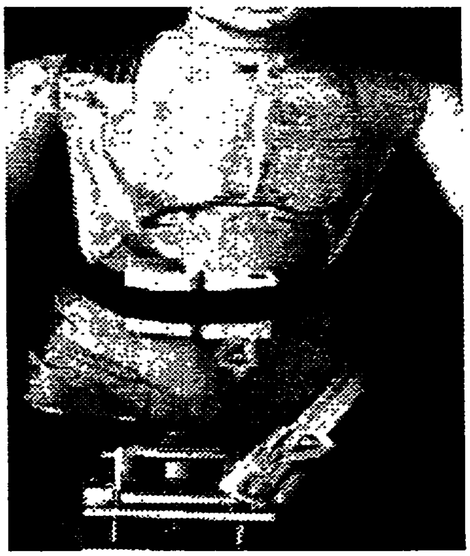

Figure 3. Pressure Sensor System. Arrays were placed in the region of shoulder straps and waist belts. Peak and average pressures were recorded.

Motion Measurements. The FASTRAK™ assessment of relative displacement between the pack and the person was validated with the OPTOTRACK™ system under both static and dynamic conditions. Results from the OPTOTRACK™ were transposed to correspond to a common coordinate system and a coincident measurement point. Regardless of test conditions, the pack/person relative positions had a .65 mm RMS error.

Biomechanical Model. The biomechanical model estimates upper shoulder strap (T2) force from the lower shoulder strap (T1) tension, the shoulder wrap angle (θ) and approximations of the frictional forces (μ). The first step of the validation involved determining μ by two independent strategies. One calculation technique involved using the values for the upper and lower strap forces and the angle of wrap, while the second incorporated the pressure generated under the strap with the two strap forces. There was no significant difference in the results from the two different methods ($R^2 > .92$).

CONCLUSION

A summary of the significant findings from the validation and reproducibility studies is tabulated below These results are based on test-retest or repeated measures of two packs; one military (c) and one civilian (D).

Test Parameter and Method of Validation	Results - Accuracy Precision and Reproducibility
Strap Force Transducers	
Static - Strap transducer response versus calibrated weight Dynamic - Independent level walking tests, CF 1982 pattern load carriage	Test range 0 - 100 N, SD Waist = 1 5 N, Shoulder = 2 6 N, SD (independent tests) Waist = 0 9 N, Shoulder = 0 3 N SD (all tests) Waist = 2 4 N, Shoulder = 2 3 N Decay over 1200 cycles <4%
Pressure Distribution	
Static - Independent tests, CF 1982 pattern load carriage and Gregory Dru backpack	Good test to test correlation of average pressures Good agreement of average pressure with previous report Confirmation of pack rank orders from previous tests
Dynamic - Test/retest of CF 1982 pattern load carriage and Gregory Dru backpack	Good test to test correlation of average pressures SD (average pressures, 1200 cycles) 2 6 kPa Samples needed for SEM<2.0 kPa n=2
Dynamic - Independent level walking tests, CF 1982 pattern load carriage	Good repeatability on the locations of peak pressures Marginal repeatability on the magnitude of peak pressures SD (peak pressures, 1200 cycles) 12 6 kPa
Relative Displacement of Pack	
Static - Fastrak™ data versus Optotrak™ displacement data Dynamic - Independent level walking tests, Fastrak™ data versus Optotrak™ data	RMS error (relative pack/head displacement) 0 65 mm Relative displacement (peak to peak) Fastrak = 5 3 mm, RMS error (relative pack/head displacement) 0 65 mm

* Statistical analyses were either test-retest or repeated measures designs

Acknowledgements: *This project was performed under contract from the Defence and Civil Institute of Environmental Medicine, Contract #. W7711-4-7225/01-XSE, 1995-1996.*

Integration of Subjective and Objective Analysis Systems into a Standardized Measurement Approach

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Abstract - A programmable pneumatic motion simulator, with three degrees of freedom; vertical displacement, forward and side rotation, was developed to evaluate a variety of load carriage systems (typically backpack based). A model of a human torso with a compliant surface was then displaced to simulate level walking. The test parameters were: skin contact pressures, strap forces and relative displacement of the pack with respect to the person. Results of the simulator tests were compared to subjective evaluations of the Load Carriage (LC) systems during agility and extended hiking tests to validate the simulator results. Design evaluations performed on the simulator were shown to be predictive of user acceptability.

INTRODUCTION

This research correlated the results from human and simulator testing to create a standardized evaluation tool for assessing load carriage designs. This evaluation protocol will be used in the development of an Advanced Personal Load Carriage System (APLCS) for the Canadian Land Forces. A detailed system and design analysis of human load carriage, as well as a design review was conducted to understand load carriage demands and to study the features and functions of current military and civilian load carriage systems. Subjective and objective data were gathered on five backpack designs Comparison of these indicated a predictive agreement between physical measures, and human factors measures, i.e. Load Carriage (LC) Simulator results and a packs' mechanical properties can predict the effect of a backpack design on a user's performance and comfort.

METHOD

Objective Evaluation: The LC Simulator consists of computer controlled pneumatic actuators programmed to vertically displace a model of a human torso in a sinusoid to replicate slow level walking (60 steps/minute, amplitude +/- 15 mm), Figure 1. Each load carriage system was placed on the torso, then the shoulder straps and waist belt were set to strap tensions measured on humans. Tekscan™ pressure sensor arrays were placed under contact points on the shoulder, lower lumbar region and hips to determine the magnitude and area of contact pressures. Fastrak™ 3D displacement transducers were mounted on the pack and torso to measure the relative motion of the LC suspension system. Custom built strap force transducers were used to measure strap forces. These data were subsequently used in a biomechanical model to predict the force distribution between the pack and the torso.

Subjective Evaluation: Human performance evaluations were based on a mobility circuit designed to simulate specific survival skills. Twenty soldiers assessed their agility, load control, and comfort while testing three military systems, one internal, and one external frame civilian pack, Figure 2 These same packs were worn by 20 soldiers during an extended 6 km march while carrying 32 kg which reproduced marching order mass. Strap forces, body lean, and regions of discomfort were assessed to compare subjective responses with biomechanical modelling, pack geometry, inertial and stiffness properties, and LC Simulator findings.

MAIN FINDINGS

Factors Affecting Agility Performance

Physical Properties of the Pack: The overall length of a pack correlated weakly with the agility score (r^2=0 57). Within this study, agility scores were not shown to be related to the relative position of the centre of gravity above the iliac crest, or to the moment of inertia about the vertical axis.

Pack Suspension: Pack suspension is the interface between the carried load and the body. A stiff suspension will allow little relative motion between the pack and torso. Relative displacement between the pack and the torso was measured on the LC Simulator for level walking. An r^2 value of 0 70 was found between the vertical motion of a pack and the agility score given to the pack, indicating that the ability of a suspension system to control the relative motion between the pack and torso influences performance in agility activities. The torsional stiffness of a pack design was also found to be inversely related to the agility score.

Factors Affecting Endurance Performance

Contact Pressures: Lumbar pad pressures showed a correlation with subject discomfort scores, (r^2= 0.65), while contact pressures in the shoulder did not. This result is contrary to the maximum safe skin contact pressures indicated in other studies [1,2]. If unrelieved, high contact pressures under the shoulder straps could result in chronic problems not detectable in a 6 km march .

Contact Forces: Lumbar contact forces and shoulder reaction forces were predicted based on a biomechanical model. A correlation of $r^2 = 0.93$ was found between the lumbar force and discomfort with weaker correlations between the shoulder force and user discomfort.

CONCLUSIONS

Relative Motion between Pack and Torso: LC Simulator results indicated that relative motion in the Z direction should be constrained to less than 20 mm. Relative vertical motion greater than this was related to poor performance on agility tests, (r^2=0.70).

Contact Pressures: Studies of contact pressures indicate that maximal skin pressure should not exceed 10-14 kPa to ensure tissue viability[1,2]. With a 32 kg load, the average pressure under shoulder straps and lumbar pads exceeded these limits in some designs. Peak pressures exceeded this physiological limit for all designs. Discontinuities on the shoulder strap upper surface were the major factor in the creation of peak pressure points. The presence of a buckle on the upper surface of the strap, created a peak high pressure zone. As well, discontinuities beneath the strap, such as seams or pockets in clothing, also caused high pressure zones. This suggests that consideration be given to the design of clothing to accommodate the contact between straps and torso.

Force Distribution between Pack and Torso: Based on discomfort ratings assessed during 6 km marches with a 32 kg load, design limits for contact forces were established as 135 N for lumbar pads and 140 N per shoulder for the total shoulder reaction force (280 N total). Studies suggest that on average, *in-vitro* failure of the lumbar spine will occur at 430 N of shear and 3340 N of compression (moments of 140 Nm)[4], these criteria are a reasonable starting point as a design guideline.

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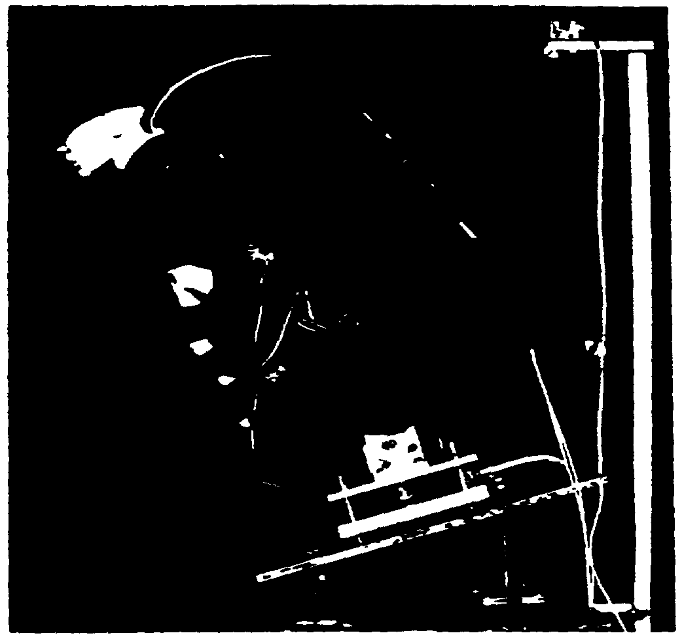

Figure 1: Load Carriage Simulator

Figure 2: Agility circuit, assessing load control in a simulated boulder hop.

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Optimal Load Distribution

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Introduction

The present study has been initiated in the framework of the Advanced Personal Load Carriage Systems (APLCS) Project. The objective of this project is to provide modelling and computational tools to evaluate the effect of three-dimensional loading configurations (in particular, backpack loading) considering multiple criteria. These criteria include the following:

i. basic physical constraints (fit, tightness, stability of packing);
ii. balance, target centre of gravity (CoG) of load (aiming eventually at carrying comfort);
iii. importance ranking (ease of accessibility) of packed items;

and possibly some other aspects

On the basis of such criteria, recommendations related to good ('optimal') packing strategies are to be made.

The optimization software is intended as a design aid. This computer simulation would permit the user to evaluate the effect of varying the pack dimensions as well as different kit combinations on the centre of gravity of the load carriage system, and ultimately the resulting forces on the bearer. The static advantages of a tall narrow pack could be compared with squat versions for a wide range of kit. Furthermore, the kit would not be considered simply as a point mass, but the volumetric and accessibility constraints would be met.

Related Literature

The literature related to this study is drawn largely from the operations research journals. No articles have been found in the area of ergonomics nor any other discipline which would have an interest in load carriage. A complete literature review is available in Pinter & Pelot, 1996. Below, the salient points are presented.

This kit placement problem is closely related to packing and loading issues which are subjects of ongoing research in the operations research literature. The usual context is to determine the best way to load a set of identical or non-uniform objects onto or into a carrier. Pallet loading and aircraft cargo loading are two common examples. These problems are very difficult integer programming problems, and no general solution has been developed. The usual approach is to develop a heuristic for a sub-class of problems whereby the objects are loaded sequentially making efficient use of remaining space. This produces good, but not necessarily optimal, solutions.

There is a critical distinction however between all of these preceding analyses, and the current study. In the case of volumetric packing, the effect of the next object placed is immediately known, i.e. what space it occupies There is no aggregate measure involving all of the objects simultaneously that affects the global outcome In contrast, for the kit placement problem, the principle measure relates to the centre of gravity of the whole system which cannot be optimized by a sequential packing approach. Thus this problem is more complicated than existing published results. The category of methods in which this problem falls is referred to as mixed-integer non-convex global optimization There is no commercial software which can solve this class of problems, so part of this study involves developing specialized solution techniques.

Model Formulation

Using quantitative modelling terminology, the basic task can be expressed as follows: given a physical load area (a three-dimensional volume of given shape) and a number of objects, place these objects into the load area in an 'optimized' fashion, as determined by a given set of criteria.

- *Input data:*
  Container: 3 dimensions and mass
  Kit: 3 dimensions, mass and accessibility rating (given say 3 classes of priority) for each item
  Target location centre of gravity: the user specifies the "ideal" CoG for combined container and kit. This can be derived from a biomechanical model of forces on the bearer, once completed, or a series of varied CoGs to study the sensitivity to kit location.
  Target attractor point. to keep objects from "floating in the air" and/or having large gaps between them, a point is defined (typically in the bottom centre of the pack) to which the kit items are attracted

■ *Objective function:*
There are several objectives to be satisfied simultaneously.

1. minimize the sum of the absolute values of the difference between each item's centre and the "attractor point" to keep objects from floating;
2. minimize the Euclidean distance between the aggregate centre of gravity of all of the kit items plus the container and the prescribed centre of gravity;
3. maximize the relative accessibility of higher priority items

The goal is for the program to determine the best combination of decision variables (see below) which will best optimize the above criteria, subject to constraints on the system. When there are several objectives, one may be retained and the others converted to constraints, or they may be combined into a single objective with the user according a suitable magnitude to each element

■ *Decision Variables:* These are the values that the computer must produce as output.
Southwest vertex of each item
Orientation of each item

These outputs will completely specify the location of each kit item in the container.

■ *Constraints.*
Basic physical bounds on location of items (i e ensures that items are completely within pack boundaries);
Non-overlapping packing of items: to ensure that no parts of any two items occupy the same physical space. This constraint is formulated by ensuring that in at least one of the orthogonal directions the distance between the centrepoints of two objects is greater than half the sum of their widths;
Accessibility (priority ranking). the current version requires that the top of any higher priority item not lie below the top of any lower priority item

This latter constraint can be dealt with as an objective function component instead.

Pilot Tests

Ergonomic studies using test dummies, and real (human) exercises with given loads have been and are being accomplished. related to this project. This provides preliminary information on a "desirable" centre of gravity

A list of twelve kit items which are typically loaded into the main compartment of the Canadian rucksack was prepared for the initial model testing Commercial software GAMS (Brooke et al., 1988) using the MINOS non-linear solver was used to run the program Since this package was not designed to solve integer or non-convex problems, it was not able to produce an optimal solution.

The number of kit items was reduced to five Although this set of items is not practical, an optimal solution was found, confirming the validity of the problem formulation. The procedure required declarations of the relative weights assigned to the various objectives as described above The output coordinates are written into a file, and can be read in by an AutoCAD program (Hall & Pelot, 1996) designed to draw and place the kit items in their appropriate locations in the pack

Discussion

The optimization model is a powerful simulation tool to allow sensitivity analysis for pack design, kit selection and placement, and potential trade-offs between accessibility and other considerations such as load balance. The formulation is comprehensive, but the solution techniques for this class of problems require further development to produce robust solutions to practical problems More research must be undertaken in this area. The AutoCAD interface provides a rapid evaluation tool for visualizing the results and further enhancing the prototype model

In future stages of the APLCS Project, this model will be connected to related ergonomic studies (conducted by ERG at Queen's) This will allow one to estimate the overall effect of loadings on the human body, and hence to determine good packing strategies for selected collections of items, and optimal pack shape

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Key Issues in Load Carriage

Focus Group Results

All delegates were given a ballot which allowed them to rank the five most significant design issues for military load carriage. The issues identified were collated into thirteen groups. Scoring of issues was based on the rankings of each individual ballot (5 points for #1 rank, 4 points for #2 rank, etc.). From this work, the five most significant issue groups, based on total score, were identified and are described in Table F.1. Table F.2 lists other load carriage issues identified during group work.

Table F.1. Key issues in load carriage, with survey scores and key words.

Rank	Issue	Score (Total / # of ballots)	Key Words
1	Adaptability	(101 / 33)	-flexibility -mission specific -task specific -individual/gender specific -load sizing
2	Integration	(95 / 25)	-system -clothing -protection
3	Load Distribution	(82 / 25)	-centre of gravity -stability -front versus back -waist versus shoulder
4	Weight	(65 / 17)	-weight reduction -limits and optimization
5	Heat Stress	(51 / 21)	-control of temperature -microclimate -physiological effects

Table F.2. Other design issues in load carriage.

Issue	Key Words
Physiological Factors Biomechanical Factors	-gait effects -muscle effects -comfort -capacity
Design Parameters	-durability -ease of manufacture -materials -design tradeoffs -access to users groups -design details (water carriage, hip belt, frame sheet) -identification of key parameters
Environmental Effect	-task requirements -self-sufficiency
Performance Measures	-mobility -criteria -donning and doffing -specifications -methods -stealth -volume
Evaluation Methods	-perception versus reality -quantitative versus qualitative
Novel Approaches	-exoskeleton -walking sticks -other vehicles -springy poles, head carriage
Protection	-environment -injury -ballistic
Process	-foresight -co-operation

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14. ABSTRACT

(U) The Workshop on Advances in Personal Load Carriage was held at Queen's University from October 7-10, 1997 and was sponsored by TTCP-TLG-8 and the Defence and Civil Institute for Environmental Medicine. The purpose was to bring together researchers with soldier mission command to exchange information between TTCP (NATO) countries and ensure that research developments were in agreement with command expectations. Commercial designers were also invited. A secondary purpose was to demonstrate the approach being taken by Canada at Queen's University, mainly the development of standardized testing protocols, such as the Load Carriage Simulator.
The conference attracted fifty scientists, soldier command, and commercial visitors from 10 countries. There were fifteen papers delivered as well as demonstrations of military and commercial systems, with abstracts included in this report. Within the program were also opportunities for discussion of system designs and design features that were important for soldier operational effectiveness. At the closing of the meeting, participants completed focus group discussions identifying key design issues in load carriage. Ideas for design to overcome current limitations were also discussed, focusing on controlling the weight, cooling the body, reducing the load, off-body load carriage, and protecting the soldier. This information is also included in this report.

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